X-713-65-373

NASA TM X-55334

N66-11229
(ACCESSION NUMBER)

16
(PAGES)

(NASA CR OR TMX OR AD NUMBER)

(THRU)

1
(CODE)

03
(CATEGORY)

FACILITY FORM 602

SOLAR CELL CALIBRATION TECHNIQUES

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

SEPTEMBER 1965

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

X-713-65-373

SOLAR CELL CALIBRATION TECHNIQUES

by

William G. Gdula
Radiometry Group
Thermal Systems Branch
Spacecraft Technology Division

September 1965

Goddard Space Flight Center
Greenbelt, Maryland

BLANK PAGE

SOLAR CELL CALIBRATION TECHNIQUES
(Development of Instrumentation and
Techniques for Accurate Measurement
of the Basic Properties of Solar Cells.)

by

William G. Gdula*
Radiometry Group
Thermal Systems Branch
Spacecraft Technology Division

ABSTRACT

11229

Efforts to develop the measurements of absolute quantum yields, surface reflection losses, diffusion lengths, and junction properties of solar cells and related detectors used in the Radiometry Section are continuing.

The grating monochromator system used for the quantum yield measurement is undergoing basic improvements required for more accurate measurements.

Solar cell measurements are briefly described with their practical applications.

Author

*Taag Designs, Inc. employee at GSFC – Contract #NAS 5-2382.

PREFACE

The current effort of the program is essentially a re-activation of efforts begun in September, 1962. This is the first Quarterly Progress Report covering the initial work. There has been an attempt to effectively broaden the scope of the program in order to keep more in line with the responsibilities of the Group. There is presently, one principal contributor, with added support expected in the near future.

In consideration of the new contracting procedure expected, it is felt that the quarterly report should be prepared in a more formal presentation. Some redundancy is evidenced for the sake of clarity of content.

The work described in this report was supported by ART Work Unit Number 123-33-01-01 (Solar Cell Calibration Techniques) under the technical direction of Charles H. Duncan.

SOLAR CELL CALIBRATION TECHNIQUES

I-A. PROGRAM OBJECTIVES

Solar Cell Calibration

The primary objective of the solar cell program in the Radiometry Section is to develop the instrumentation and capabilities necessary for accurate measurement of the basic properties of solar cells. These measurements are fundamentally important to the solar cell manufacturers, satellite power supply designers and investigators of radiation effects in solar cells.

I. Major emphasis is being placed on measuring the absolute spectral response of solar cells. The present spectral response measurement system is composed of a high efficiency 1 meter Czerny-Turner type grating monochromator made by McPherson Instrument Corp. External optics, detectors and electronics were supplied by Brower Laboratories. In addition to the standard technique for measuring the spectral response, a reflectance sphere attachment with the necessary electronics is being provided to correct the spectral response for monochromatic energy which is reflected from the cell surface. These spectral response measurements will be supplemented by an auxiliary system composed of a high intensity light source, narrow-band interference filters contained in an automatic projection mechanism and a Gier-Dunkle integrating sphere. The point by point filter technique enables the solar cell spectral response to be measured at monochromatic energy levels several decades higher then a conventional monochromator.

II. The I-V characteristics of individual cells and modular strings will be measured in environmental conditions simulated as accurately as the existing states of technology allow. To accomplish this objective, a complete environmental test facility has been developed by G.E. and is presently undergoing final systems acceptance criteria. The 3-1/2 cubic foot ion-pumped test chamber is capable of reaching vacuum conditions greater than 5×10^{-11} mm Hg. The entire volumn is thermally controlled from -50°C to 250°C by a single fluid recirculating system with exacting temperature control. Two twelve inch quartz ports will enable the solar cells to be illuminated by a state-of-the art solar simulator, the Spectrolab X-25.

III. Diffusion length measurements by ionizing radiation will be made to support the spectral response measurements. Elementary theory dictates that the spectral response at low photon energy levels is determined by this "effective diffusion Length." An Elcor current integrator, Faraday cup with sample holder and use of a 1 Mev electron generator are required. The measurement technique developed by Rosenzweig of BTL is straightforward and modest amounts of time and money are warranted.

IV Preliminary efforts will be started to measure the dynamic operation characteristics of solar cells to be used as detectors in the Thermal Systems Branch Environmental Test Facility. These measurements will include the cell junction capacitance and conductance at increasing levels of illumination and temperature. A Wayne-Kerr Impedance Bridge, Rhode & Schwartz signal generator and necessary support instrumentation have been ordered for this investigation. In order to specify the qualifications of any detector, several properties must be defined. These are:

1. Detectivity* (for a solar cell this is equivalent to decton-hole pair per photon)
2. Detector impedance at short circuit current
3. Detector capacitance at short circuit current conditions
4. Detector shunt and series resistance
5. Detector response time — obtained from the product of junction impedance and capacitance at zero bias.

II-A. ABSOLUTE QUANTUM YIELD

Various problems were immediately encountered when attempting to measure absolute quantum yields of solar cells. The technology of absolute calibration is inherently difficult. In order to improve upon the initial accuracy of the McPherson system, the existing strip chart recorder was removed and replaced by an X-Y plotter. A digital voltmeter was installed to allow for o and full scale calibration of the plotter and overall system. This reduced the errors from the ratioed output to the recorder to less than 0.4%. However, it was found that the ratioing accuracy during any given scan varied from 1.5 to 2% and became very unstable at ratios less than 3:100.

Two function generators with a required year train were installed on the McPherson; one provided the wavelength drive for the plotter X-base and the other converted spectral response (equal energy) to quantum yield - equal photon densities.

In addition to the above modifications several improvements are being made. The existing light source and detector housing assemble were not adequate for the accuracy and flexibility required. These have been removed and assemblies have been designed. Finished drawings are expected to be completed by June, 20.

The vibrating wedge chopping and beam splitting assembly has been modified. A rotating sector wedge with a frequency shift from 6.66 to 11.2 cps will be installed when the detector housing assemble is completed.

There have been considerable improvements made in the Brower design of the synchronous detector amplifier system since being developed two years ago. The improvements which are planned to be incorporated into the Model 114 include:

1. Replacement of preamplifier with new model for greater stability and less pick-up.

2. Redesign of the multiplex amplifier to allow increased stability at ratios approaching 1:100.

3. Stabilization of the D.C. coupled amplifier.

4. Provide buffer output amplifier with 10r output.

5. Convert chopping frequency from 6.6 to 11.2 cps for a better S/N ratio.

Price information from Brower has been repeatedly requested for these changes but has not been received.

Measurements of spectral responses were continued for a period of time but it soon became apparent that additional improvements were needed before absolute G.Y. could be made. Figure 1 is a typical spectral response of a 10-ohm silicon cell. Figure 2 is a GaAs RCA experimental cell, showing the very sharp absorption at 8900 Å. Higher orders from the grating have not been eliminated but a filter system has been designed and will be installed in the new assembly.

A request for design and drafting services in the development of an automatic projection mechanism used for measuring absolute Q. Y. of solar cells and detectors has been processed. The complete system will use a 1600 watt Osrom Xenon 1 amp with the Balzors narrow-band interference filters. No completion date has been offered by the Fabrication Division.

II-B. I-V MEASUREMENTS

Current-voltage measurements of development GaAs solar cells were made for the Spacecraft Power Group at energy levels of 100 and 140 mW. There had previously been gross disparities in power outputs in going to higher radiance levels. The APL-OCLI Simulator which uses both tungsten and Xenon lamps was probably the cause. Using the Spectrolab X-25 Solar Simulator, there was less than 2% variation in outputs from all cells at the two levels. The experimental data was submitted to Cherry and during the [illegible] only a few I-V curves were retained.

As a point of interest, GaAs cells made in 1962 were tested with the latest development cells. There was virtually no improvement in efficiency. Figure 3 is a typical I-V of the new lot.

It may be stated that the bulk of the efforts in measuring e[illegible]encies by the I-V curve exhibit compl[illegible] [illegible]ocence of fundamental knowledge [illegible] spite of vast efforts in solar cell development. The dependence of the effic[illegible]y upon junction properties such as: the junction electrostatic potential, ma[illegible]e of the depletion width, recombination of minority carriers in large ar[illegible] [illegible]pletion widths, effective capacitance and cond[illegible]tance at optimum power c[illegible]ons, impurity, concentrations near the junction region etc. are prob[illegible] [illegible]s which systematic approach of solution.

II-C. DIFFUSION LENGTH MEASUREMENTS

For minority carriers which are essentially generated in the base material beyond the junction region, the bulk diffusion length is of primary importance in determining the absolute quantum yield. This diffusion length can be readily derived from an approximate solution of the continuity equation with necessary parameters obtained from experimental quantum yield, surface reflection and optical absorption date. This solution evolves to be:

$$\text{Base Response} = \frac{N_o(1-R)}{\alpha + \frac{1}{L}} e^{-D\alpha}$$

where

N_o = photon density
α = optical absorption
D = cell thickness
R = surface reflection
L = diffusion length

For large values of optical absorption and cell thickness greater than 500 microns. this simplifies to

$$\text{Quantum yield} = \frac{1}{\alpha + \frac{1}{L}}$$

At 50% Q.Y. the diffusion length is equal to the optical absorption coefficient. However, using this method, low energy (several eV) ionizing radiation, is not amenable for accurate measurements since the optical absorption coefficient must be known to a higher degree of accuracy than presently attainable.

A direct approach in measuring the "effective" diffusion length is to use high energy ionizing radiation which generates carriers uniformly in the base material. The method developed by Bell Telephone Labs with minor modifications to the Faraday Cup Arrangement will be used for the solar cell measurements.

The ionization current

$$I_s = J_B\, S_o\, L$$

where

J_B = radiation density
S_o = specific ionization
L = effective diffusion length

will be measured with an Elcor current integrator. So, which can be described as the average spatial rate of electron-hole pair production per incident particle is calculated to be 225 pairs per micron for a 1 Mev electron. The experimental procedure is straightforward and data applications are quite varied. Figure 4 shows ionization linearity curves for silicon solar cells. The slope of the curve

is proportional to the diffusion length. By use of the large dynamic range of a Van der Graaff generation conclusive linearities of solar cells can readily be obtained. Figure 5 shows another interesting application of the diffusion length measurement. Here the rate of degradation under 0.5 Mev electrons is shown for twelve solar cells fabricated from wafers cut in the ⟨111⟩, ⟨110⟩ and ⟨100⟩ planes. The linear rate of degradation lends some empirical degree of credulance to the evaluative "K" parameter derived from the well known relation.

$$\frac{1}{L^2} = \frac{1}{L_0^2} + K\Phi$$

No appreciable anisotropic effects were noted for these cells until diffusion lengths of 20-30 microns were obtained. Starting diffusion lengths of 160-175 microns general state that the cell will have current densities of 25-30 ma per cm^2 at 100 mw of energy.

The required instrumentation including an Elcor current integrator has been purchased but no equipment has been received to date. Preliminary drawings for a Faraday cup with a sample compartment have been initiated. Final drawings will be provided by the Fabrication Group.

III. PROGRAM SCHEDULE FOR JUNE 7 – August 31, 1965

A. Work will continue towards the completion of the spectral response calibration system. Upon completion of the absolute calibration, future program objectives will dictate whether the system should be digitized for rapid measurements. All detectors available will be calibrated for absolute-quantum yield responses.

B. I-V curves of representative solar cells will be made under high vacuum conditions to check for possible changes in calibrated solar cell characteristics.

C. A portable panel rack assembly containing the necessary instrumentation for the diffusion length measurement will be constructed. The Faraday cup design with a special sample compartment will be completed.

D. 1. All necessary instrumentation for measuring the junction properties of solar cells is scheduled to be received during the next quarter. With help permitting initial measurements will be made of capacitance and conductance effects of solar cell p-n junctions for different operating conditions.

2. The detectivity of selected solar cells and thermopiles will be measured using the Barnes 1273°K black body and the Brower 12g detecting system.

IV. CONCLUSIONS AND COMMENTS

Considerable planning had been given as to how the efforts of the solar cell calibration program could be more effectively integrated into the overall responsibilities of the Solar Simulation Section. The program objective as outlined in Section I-A, when completed will be a significant contribution to the Section.

The design of the absolute quantum yields calibration system has been completed and with the completion of necessary fabrication involved, it is felt that the measuring capabilities of the system will be more accurate then any available. The inclusion of the integrating sphere to measure the reflected energy provides a more meaningful criteria for solar cell evaluation and detector calibration.

It is expected that after the contract negotiation additional support may be provided to put the other areas of the outlined program on a contributing basis.

V. SOLAR CELL CALIBRATION INSTRUMENTATION
713 Y33-01

				NASA
I.	Optical			
	1. McPherson Grating Mono			
	2. Balzers interference filters (31)			
	3. Heat absorbing filters (3) 2" × 2"			
	4. Optical bench Gaertner 120 cm			38422
	(a) Nodal holder			
	(b) R. H. holder			
	5. Xenon cut-off filters (2) #26515			
II.	Detectors			
		Area	SN	
	1. Charles Reeder	1 × 1 cm	5205	
	2. Charles Reeder	1 × 1 cm		
	3. Charles Reeder	2 × 2 mm	K 5034	
	4. Charles Reeder	2 × 2 mm		
	5. Charles Reeder	1 × 2 cm	K 5237	
	6. Charles Reeder	1 × 2 cm	K 5	
	7. Eppley	C.T.	6019	

	NASA
III. Detecting Systems	
1. Brower Model 114 for McPherson	
2. Brower Model 129	162781
IV. Light Sources and Accessories	
1. Xenon lamp 900 watts (2)	
2. Slyvania Sun-Gun 500 watts (5)	
3. Hg high pressure lamp holder (1)	
4. Pulse igniter Osram (1)	
5. Pulse igniter Hanovia (1)	
6. Tungsten 1^{kw} sub-standard (1)	
V. Electronics	
1. EAI X-Y Plotter	31930
2. Wayne Kerr Impedance Bridge	164156
VI. Plastics-Adhesives-Epoxy	
1. Kenic AC-1 Silver conductive epoxy (2)	
2. Dow Corning 340 Silicone heat sink compound (4)	
3. GE RTV-102 Adhesive silicone rubber (4)	
Miscellaneous	
1. Variac W 5LMT3 (1)	
2. Voltage Regulator Sorenson Model 30005	20846
3. Precision Resistor 1-ohm Rubicon 126297	
4. Hg reference cells (6)	
5. Emcor Panel Rack (1)	
6. Tool Box TB-8 (1)	
7. Thermoelectric cooling plate with D.C. power supply. Westinghouse W 852003	
8. Sartorius Balance	45708
9. Mu-Metal Shielding (2) rolls	

VI-A. BUDGET ITEMS FISCAL 63

1. Monochromator Digitizing System	24,000
2. Brower updating of Model 114	3,500
3. Crayoflask - Hoffman Model HLOT Helium Devar	2,300
4. Off-axis collimator	3,400
5. Black Body 1000°C	1,800
6. Integrating sphere-Gier-Dunkle	4,600
7. Ion-pumped Vacuum system 1.5 ft^3	11,400
8. Detectors: Evaluation	
1. Barnes Thermistors	850
2. Philco Indium Antimonide	475
3. Solid-State Radiation Detector	500
4. Thermopiles Reeder	1,800
9. Solar Simulator	19,500
10. Solar Cells & Cover Slips	1,700
11. Adhesives, epoxies mounting substrates	1,200
12. Gaertner optical bench accessories	800
13. Variable speed chopping and synchronous detecting system Brower 130	2,900
14. (2) Engineering man-years	26,000
15. Van de Graaff time for diffusion length measurements	1,500

VI-B. FABRICATION AND DESIGN SUPPORT

1. Support assembly for integrating sphere and detector housings
2. Three-lamp water cooled assembly for monochromator
3. Automatic projection assembly for Balzers filters
4. I-V test set-up with vacuum pumping station
5. Faraday cup and sample compartment
6. Misc. cell holders and test fixtures

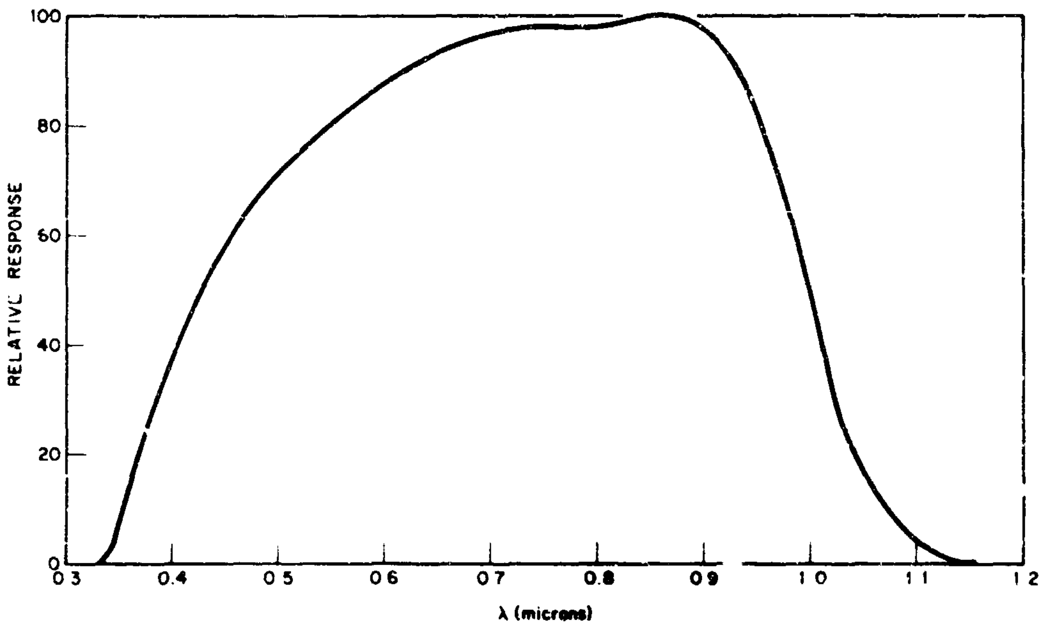

Figure 1–Spectral Response Characteristic of 10Ω Silicon Cell

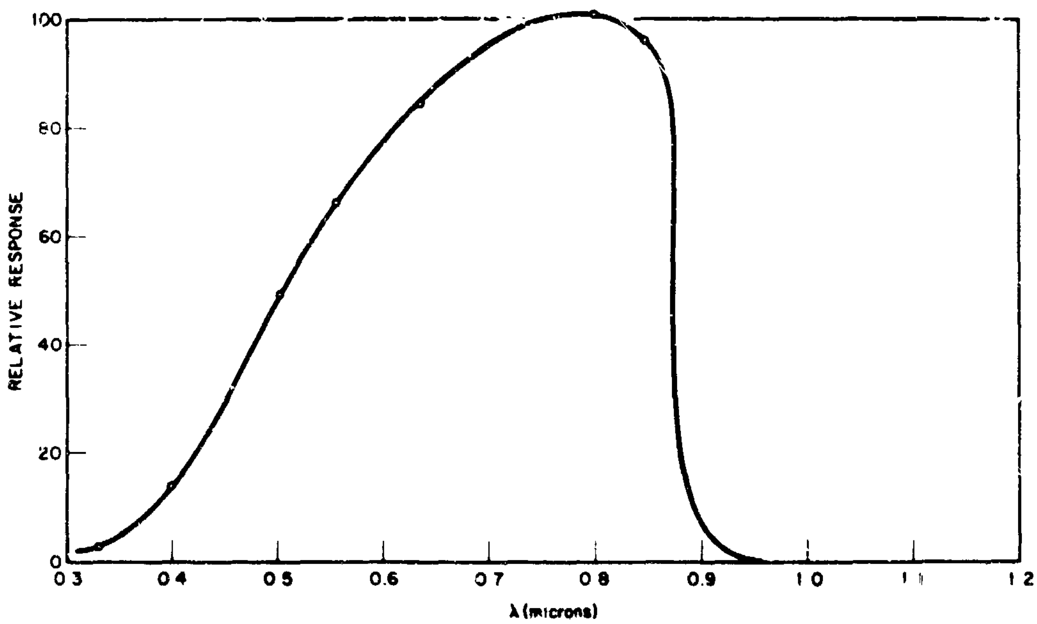

Figure 2–Spectral Response Characteristics of GaAs Cell

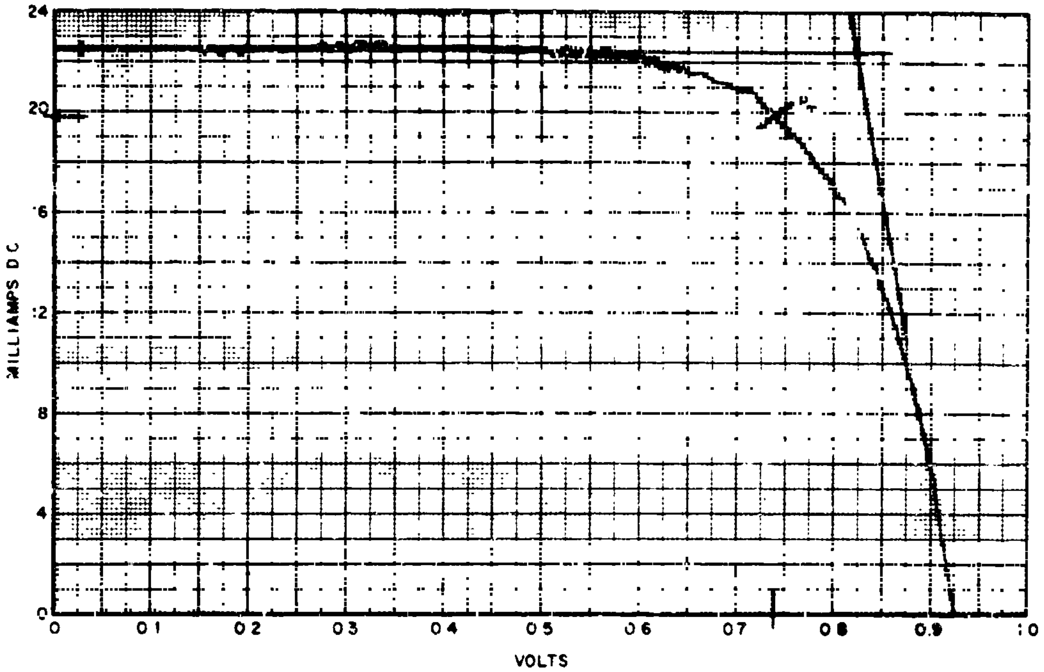

Figure 3—I-V Characteristic of GaAs Cell

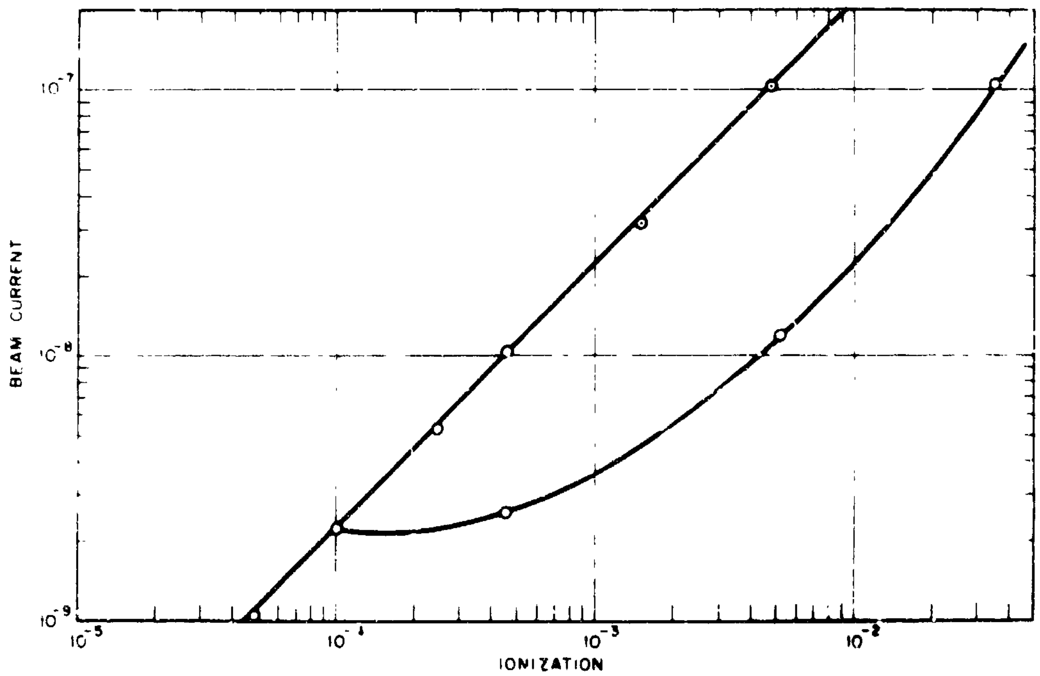

Figure 4—Ionization Linearity Curves for Si Solar Cells

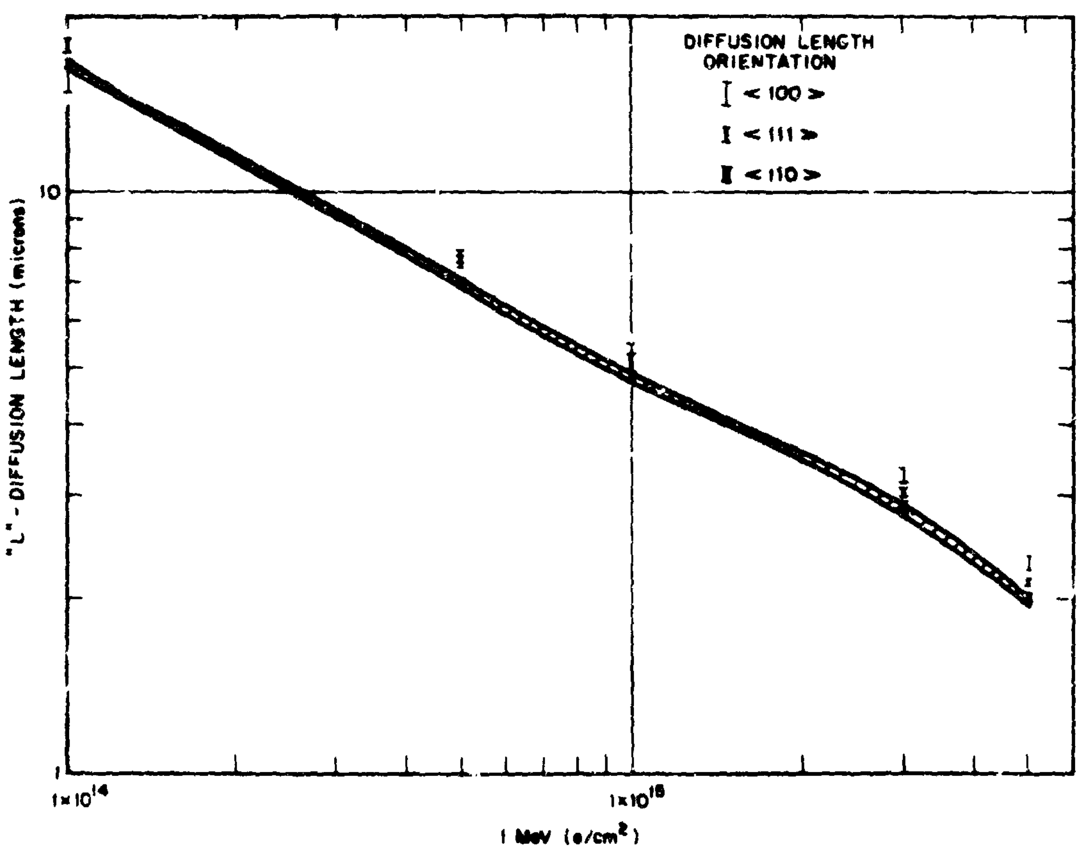

Figure 5—Degradation of Diffusion Length by 0.5 Mev Electrons